Agricultural Systems 157 (2017) 81–92

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Climate change impacts on crop yields, land use and environment in response to crop sowing dates and thermal time requirements

Andrea Zimmermann[a,*,1], Heidi Webber[b,1], Gang Zhao[b,1], Frank Ewert[b,f], Johannes Kros[c], Joost Wolf[d], Wolfgang Britz[a], Wim de Vries[c,e]

[a] Institute for Food and Resource Economics, University of Bonn, Nussallee 21, 53115, Bonn, Germany
[b] Institute of Crop Science and Resource Conservation (INRES), Katzenburgweg 5, University of Bonn, 53115 Bonn, Germany
[c] Wageningen Environmental Research, Wageningen University and Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[d] Plant Production Systems Group, Wageningen University and Research, P.O. Box 430, 6700 AK Wageningen, The Netherlands
[e] Environmental Systems Analysis Group, Wageningen University and Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[f] Leibniz Center for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, 15374 Müncheberg, Germany

ARTICLE INFO

Keywords:
Integrated assessment
Crop management
Climate change
Europe

ABSTRACT

Impacts of climate change on European agricultural production, land use and the environment depend on its impact on crop yields. However, many impact studies assume that crop management remains unchanged in future scenarios, while farmers may adapt their sowing dates and cultivar thermal time requirements to minimize yield losses or realize yield gains. The main objective of this study was to investigate the sensitivity of climate change impacts on European crop yields, land use, production and environmental variables to adaptations in crops sowing dates and varieties' thermal time requirements. A crop, economic and environmental model were coupled in an integrated assessment modelling approach for six important crops, for 27 countries of the European Union (EU27) to assess results of three SRES climate change scenarios to 2050. Crop yields under climate change were simulated considering three different management cases; (i) no change in crop management from baseline conditions (NoAd), (ii) adaptation of sowing date and thermal time requirements to give highest yields to 2050 (Opt) and (iii) a more conservative adaptation of sowing date and thermal time requirements (Act). Averaged across EU27, relative changes in water-limited crop yields due to climate change and increased CO_2 varied between − 6 and + 21% considering NoAd management, whereas impacts with Opt management varied between + 12 and + 53%, and those under Act management between − 2 and + 27%. However, relative yield increases under climate change increased to + 17 and + 51% when technology progress was also considered. Importantly, the sensitivity to crop management assumptions of land use, production and environmental impacts were less pronounced than for crop yields due to the influence of corresponding market, farm resource and land allocation adjustments along the model chain acting via economic optimization of yields. We conclude that assumptions about crop sowing dates and thermal time requirements affect impact variables but to a different extent and generally decreasing for variables affected by economic drivers.

1. Introduction

Understanding how climate change may affect European arable agriculture is important to guide decision making around possible adaptations in agricultural management, to minimize damages and realize benefits (Howden et al., 2007; Ewert, 2012; Hall et al., 2012; Vermeulen et al., 2012; Kahiluoto et al., 2014). Consideration of climate change impacts on crop productivity alone is, however, not sufficient to project how cropping patterns will respond to climate change as changes in technology, prices and trade likewise all affect agricultural management (Reilly et al., 2003). While there is an increasing number of crop modelling impact studies quantifying the impacts of climatic factors on European crop productivity (Asseng et al., 2015; Webber et al., 2015; Zhao et al., 2015b), fewer examples examine how these may translate into changes in land use and production, and the resulting impact on the environment (Reilly et al., 2003; Nelson et al., 2013; Shrestha et al., 2013). Ideally, such analysis would make use of knowledge from a suite of disciplinary models, able to simulate crop productivity and farm resource allocation as well as resource use and degradation (Antle et al., 2004; van Ittersum et al., 2008; Ewert

---

[*] Corresponding author at: Trade and Markets Division, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy.
E-mail address: andrea.zimmermann@fao.org (A. Zimmermann).

[1] Andrea Zimmermann, Heidi Webber and Gang Zhao made equal contributions to the study.

http://dx.doi.org/10.1016/j.agsy.2017.07.007
Received 5 September 2016; Received in revised form 8 July 2017; Accepted 10 July 2017

et al., 2009; Britz et al., 2012) appropriate for the scale, region and particular problem considered (Ewert et al., 2015).

While the response of crop productivity to climate change alone is insufficient, accurate estimates of how crop yields will respond to higher temperatures and changed precipitation patterns are critical to understanding the broader implications of climate change for agriculture. In their integrated assessment (IA) of climate change effects on poverty around the world, Hertel et al. (2010) demonstrated that future global crop commodity prices and poverty outcomes in 2030 were extremely sensitive to the magnitude of relative climate change impacts on crop yields. Likewise, in a global integrated assessment of climate change on global food systems, Nelson et al. (2013) and von Lampe et al. (2014) showed that their economic models were very responsive to the size of the climate change impact on crop yields. Collectively, these studies demonstrate the need for robust estimates of how crop yields are likely to respond to climate change.

The crop sowing date and choice of variety determine how much radiation is captured by the crop, a key determinant of potential yield levels (Van Ittersum and Rabbinge, 1997). As temperatures warm, phenological development accelerates and crop yields of a given variety can be expected to decline due to a shorter period to intercept radiation (Craufurd and Wheeler, 2009). The acceleration of phenology with warming has been observed across Europe (Menzel et al., 2006) with the result that longer growing seasons are possible for potential growth. Siebert and Ewert (2012) and Estrella et al. (2009) report accelerated development for a number of annual crops in Germany, though less pronounced for winter sown crops due to the buffering effect of vernalization and photoperiod responses (McMaster et al., 2008). Changes in crop phenology can be only partially explained by changes in climate; changes in crop management also change the occurrence of key phenological stages (Craufurd and Wheeler, 2009). For example, between 1959 and 2009, roughly one third of the advancement of phenological stages of oats in Germany can be attributed to the use of shorter season varieties, advised by extension services as a means to avoid later summer drought (Siebert and Ewert, 2012). Likewise, trends of earlier crop sowing dates with warming temperatures have also been observed (Estrella et al., 2009). Rezaei et al. (2015) report the sowing date for winter wheat in Germany advanced by 5 days in the period 1951–2009, while a subsequent study reported the sowing date for winter rye advanced by 1.3 days decade^{-1} whereas the sowing date for winter rapeseed remained largely the same (Eyshi Rezaei et al., 2017). These studies demonstrate both the influence of climate on sowing dates, crop development, and varietal choices, but also that other factors in addition to warming (e.g. risk of drought) influence farmers' varietal choices, which appears to vary with crop and region (Eyshi Rezaei et al., 2017). Few impact studies to date (for recent exceptions see, Webber et al., 2015; Zhao et al., 2015b) have quantified the uncertainty due to impacts of changes in crop management on crop yields (Müller and Robertson, 2014; Ewert et al., 2015). However, as sowing dates and variety choice are likely to vary with region and crop, as well as economic factors related to timing of operations (Eyshi Rezaei et al., 2017), their specification in climate change impact studies is not expected to be straightforward. Rather, it is likely to require iteration to select highest yield levels, or explicit assumptions about the criteria used by farmers to select desired management (i.e. highest yields versus drought risk management). In addition to affecting crop yields, crop management specification is expected to affect land use, total production and nutrient inputs to achieve these yields and thereby the losses of nutrients to the environment with potential adverse impacts (Reilly et al., 2003).

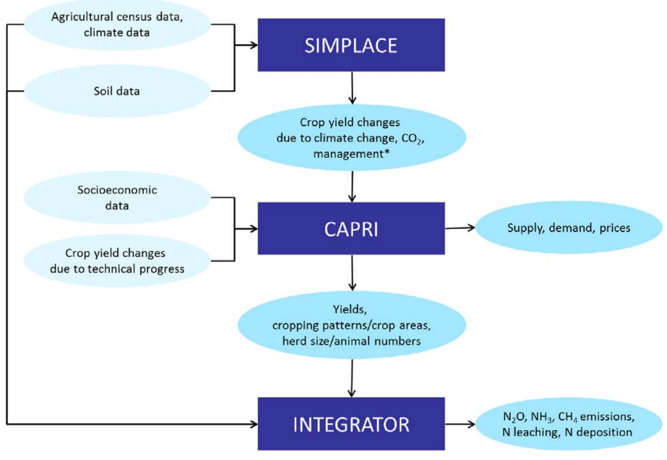
Considering both climate change impacts and the effects of specific crop management changes at all levels has rarely been done in IA assessments (an exception are Reilly et al., 2003 who assess the effects of adaptations such as irrigation water supply, pesticide use and international trade on the agricultural economy, regional crop and livestock production, irrigation water use and irrigated area, and cropland and land use). There are various literature reviews considering general adaptations in IA assessments as provided by Patt et al. (2010), Fisher-Vanden et al. (2013) and Hertel and Lobell (2014), but the "biases that are introduced when these effects are not considered in the analysis" (Fisher-Vanden et al., 2013), have hardly ever been assessed.

In this context, the overarching aim of the study was to quantify the impacts on key agronomic, economic and environmental variables for European cropping systems arising from different assumptions about crop sowing date and varietal choice (thermal time requirements) in a climate change impact study. The study was conducted with an integrated assessment modelling (IAM) framework for 27 countries of the European Union (EU27) using three disciplinary models (crop, economic and environmental).

2. Methods

2.1. Integrated modelling approach

A suite of three disciplinary models, the crop-growth model in the SIMPLACE framework (Gaiser et al., 2013) combining the models Lintul-5 (Wolf, 2012), DRUNIR (Spitters and Schapendonk, 1990; Van Oijen and Lefelaar, 2008) and Heat (Eyshi Rezaei et al., 2013), the economic agricultural sector model CAPRI (Britz et al., 2006; Britz and Witzke, 2014) and the environmental impact model INTEGRATOR (de Vries et al., 2011; Kros et al., 2012), were applied together for Europe in an integrated assessment modelling (IAM) exercise. Individual models conducted simulations for a baseline period, as well as, under different climate change and socio-economic scenarios centered around 2050. While the spatial and temporal resolution, the extent of input data and the base simulation unit differed between models, results were aggregated to and passed between models at the level of the NUTS2 administrative regions (see http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction). The main input and output relations between the data sources and models are shown in Fig. 1. SIMPLACE simulated water-limited growth and development of six crops in response to climate, CO_2 concentration, and crop management (sowing dates and varietal thermal time requirements) in three specifications. Relative yield changes due to climate change and management adaptation were determined for each scenario, relative to the SIMPLACE baseline, and passed into the economic agricultural sector model CAPRI. CAPRI also requires an input on the relative yield changes due to technology progress, and this was estimated using historical yield trends, modified for each SRES scenario following the approach of Ewert et al. (2005). The two sources of yield change were summed and passed as input to CAPRI as exogenous yield shocks.



* Adjustment of sowing dates and thermal time requirement

Fig. 1. Information flow between data sources and models including simulated impacts as used and simulated in this study.